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Evaluating Limb Asymmetry and Muscular Adaptations in Collegiate Athletes Engaged in Sports Involving Asymmetrical Movements

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1. Abstract

This study measures and compares the strength of the wrist flexor and extensor muscle groups, grip strength, and measurements of the forearm and hand to assess patterns of asymmetry between the dominant and non-dominant limbs of collegiate athletes who practice asymmetric sports compared to a reference population of college students. Utilizing a custom-built device, we recorded the maximal forces generated during wrist flexion and extension in a standardized position, and also measured grip strength in a sample of n= 26 undergraduate students to establish normal variations in strength and asymmetry. We then compared this data with athletes practicing asymmetrical sports, such as tennis and golf. We hypothesize that athletes who practice asymmetrical sports will exhibit a higher degree of muscular asymmetry, characterized by distinct patterns unique to each sport and reflective of its specific motion requirements. By measuring wrist flexor and extensor strength, this study fills a critical gap in current knowledge, offering insights into the muscular adaptations associated with asymmetrical sports and the broader field of phenotypic plasticity.

2. Introduction

Past research has documented that collegiate tennis players possess both greater grip strength and a greater degree of grip strength asymmetry than nonathletes.[1] This is because of the biomechanical demands that playing tennis requires, which causes players to predominantly use their dominant hand and arm, leading to muscle overdevelopment in those areas compared to their non-dominant limb. Grip strength is largely produced by muscles in the anterior (flexor compartment) of the forearm that originates around the medial epicondyle.[2] While grip strength is important in tennis and other sports, the muscles that act as extensors of the wrist and digits are also essential, especially in backhand movements. Repetitive backhand movements are known to be associated with an increased frequency of lateral epicondylitis, more commonly known as “tennis elbow”, which is an overuse injury affecting the common tendon of the extensor muscle groups.[3,4] This condition is extremely common among tennis players. Approximately 50% of players can expect to get tennis elbow at some time during their playing lifetime, and in one-third of the the people affected this will be severe enough to interfere with their daily tasks.[10]

Participating in asymmetrical sports has been demonstrated to result in asymmetrical muscular development among athletes, often leading to one side of the body being significantly stronger than the other. This phenomenon illustrates phenotypic plasticity, wherein the body adapts its structure and function to meet the specific demands of the sport. Handball, for example, has been demonstrated to induce asymmetrical hypertrophy in the musculature of professional athletes. It was seen that the total muscle mass of the right side of the body is significantly higher compared to that of the left side. Additionally, bilateral variability in the grip strength of the hands was also determined to be statistically significant. Research indicates that participation in this sport leads to notable differences in muscular development between the right and left sides of players' bodies.[5]

Studies done with football athletes have also shown to result in greater body asymmetry. Asymmetries between limbs were significantly larger in the more experienced players than the less experienced players for tibial mass, total cross-sectional area, and stress-strain indices. No significant asymmetry was evident for total volumetric density. More experienced players also exhibited greater lower-body tibial mass, volumetric density, cross-sectional area, stress-strain indices, fracture loads, and muscle mass and cross-sectional area than less experienced players. Both training intensity and asymmetrical loading influence changes in lower-body musculoskeletal properties. More extensive training led to greater adaptations, while prolonged asymmetrical loading resulted in distinct morphological differences between limbs. Notably, the kicking limb displayed enhanced bone strength adaptations.[6]

Higher degree of asymmetry has also been shown to be present among padel players. Research has shown that male padel players exhibit higher levels of upper limb asymmetry compared to female players. Additionally, there are variations in asymmetry among different player categories, suggesting that factors like skill level and training intensity influence the degree of asymmetry in young padel players.[7]

Despite the numerous examples of asymmetry in athletes, the degree to which wrist flexor and extensor strength are affected has not been quantified. A simple assessment of grip strength does not necessarily capture the strength of the extensor muscles, or even necessarily apply to the other muscles that act to flex the wrist (not digits). Wrist extensor muscles in tennis, especially during the backhand stroke, are crucial for controlling racket head movement and generating spin on the ball. However, overuse or improper technique can lead to injuries such as tennis elbow (lateral epicondylitis) due to repetitive strain on these muscles and tendons, impacting player performance and longevity. Having a better understanding of how tennis impacts these muscles is therefore crucial for injury prevention and better performance. This project will generate data to fill those gaps.

Many devices are commercially available to measure handgrip strength, and grip testing is frequently done in a wide range of clinical and experimental settings.[11,12] However, accurately measuring the strength of the extensors and flexors of the wrist is more difficult, and there are no widely used equipment or protocols for testing these parameters. Testing the anterior and posterior forearm muscle groups will enable us to generate novel data for comparing the relative strength of the flexor and extensor muscles, and for assessing differences that exist between an individual's dominant and nondominant limbs to quantify the potential patterns of asymmetry.

This project employs a novel technique for measuring forearm flexor and extensor strength, to establish the normal range of variation in these muscle groups and document the normal range of variation in asymmetry between the limbs. These data will provide a framework to assess these parameters in athletes who practice asymmetrical sports, such as tennis and golf. We hypothesize that there will be a greater degree of asymmetry in all measures of limb strength in the asymmetrical athletes than in other populations.

These comparisons will generate new insights into differences in muscular adaptation and physiological responses to asymmetrical training and into the broader field of phenotypic plasticity.

3. Materials and Methods

The research protocol employed was approved by the University of North Carolina Asheville Institutional Review Board. Participants in this study included n=26 undergraduate students (7 males and 19 females), n=16 collegiate tennis players (8 males and 8 females), and n=8 collegiate golf players (all female) from the NCAA

Division 1 teams at the University of North Carolina Asheville. No subject in the study reported a history of elbow, forearm, or hand problems.

Morphological measurements of forearm length (from the tip of the olecranon to ulnar styloid process), forearm circumference (two fingers distal to elbow crease), hand length (from the distal wrist crease to the tip of middle finger), and hand width (from bottom of pinky finger to bottom of index finger) were taken on each participant in the study. A tape measure was used to assess these values on each subject, and the measurements were recorded to the nearest 0.1cm.

To quantify the strength of the wrist flexor and extensor muscles, we constructed a device that keeps the limb in a standard, repeatable position while the subject pulls and pushes on a handle to measure wrist extension and flexion, respectively. The device consists of a wooden frame that anchors a commercially available force plate (Vernier FP- BTA). The force plate is equipped with a handle that the subjects grasp while maintaining constant elbow and wrist position. The force plate can record both “pull” (wrist extension) and “push” (wrist flexion) forces as the subject pulls up and pushes down on the force plate (Fig.1-A).

Fig.1-A, Fig.1-B. Measurement of forearm and hand strength. (A) subject position while measuring wrist flexion and extension. (B) Position for measurement of grip strength.

Prior to collecting any data, participants were instructed on how to use the equipment and shown a demonstration by the investigators. While measuring wrist strength, subjects were seated on a lab table, with their elbow resting on the stand that holds the force plate. With the palms pronated, subjects grasped the handle on the force plate and then alternated between pulling and pushing on the handle. Pushing down on the handle recorded the strength of the wrist flexor muscles (anterior compartment of the forearm) while pulling up on the handle recorded the strength of the wrist extensor muscles (posterior compartment of the forearm). Subjects were asked to give maximum effort for a total of 10 repetitions, 5 using the flexor muscles and 5 using the extensor muscles, alternating between pulling (extension) and pushing (flexion). Each repetition lasted around 2 seconds with a rest of 2 seconds in between each movement. Subjects repeated this activity with both hands.

In addition to assessing the strength of the forearm muscles, we also conducted measurements of hand grip strength. The apparatus and position used was the same as used to measure wrist flexor/extensor strength. However, in this test, subjects positioned their arms in the reverse orientation, affording enough room to accommodate the hand dynamometer.

To quantify grip strength, subjects were seated in the same exact position, with their elbow and forearm resting on the apparatus while they squeezed a hand dynamometer (Vernier Systems, HD-BTA). Subjects were instructed to exert maximum effort while squeezing the dynamometer for five repetitions, each lasting approximately 2 seconds, with a 2-second rest period between each repetition. They were instructed to maintain a protonated hand position to compare with the wrist position in the other experiments (Fig1-B).

This process was repeated for both hands. Subjects were randomly assigned to determine whether wrist strength testing or handgrip strength testing was performed first. The data analyzed were the maximum of each of these parameters, determined by compiling the highest peak value observed in each trial (Fig. 2).

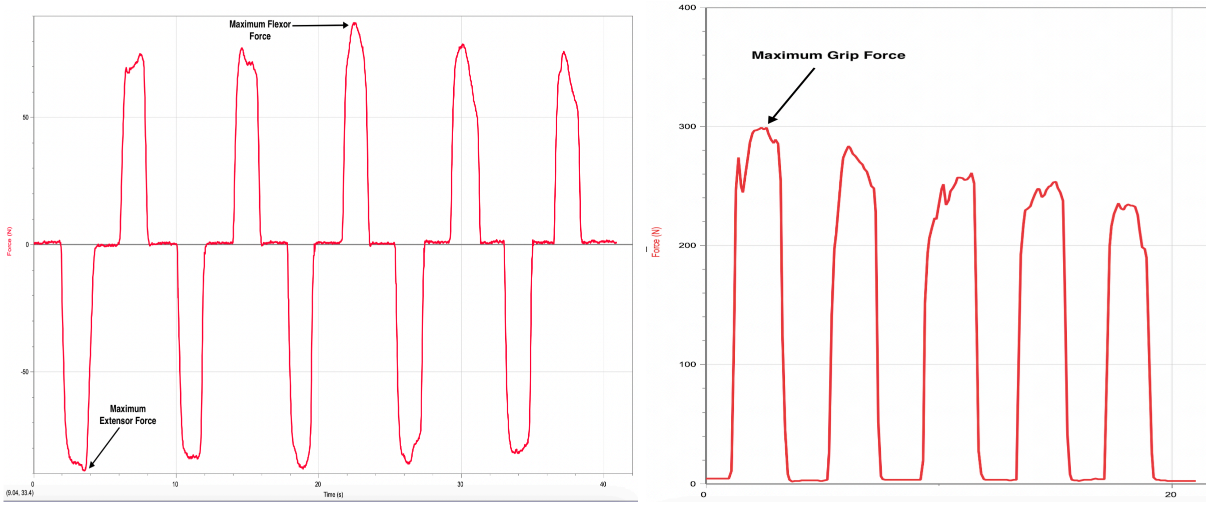

Fig. 2. Example of data generated when subjects performed wrist flexion/extension and used the hand dynamometer to measure grip strength.

4. Results

4.1. Morphometric Analysis

Significant differences were identified between the dominant and non-dominant forearms and hands among tennis players in all 4 measurements: forearm length (Paired T-test: one-tailed t= 1.76, df= 14, P= 0.002), forearm circumference (Paired T-test: one-tailed t= 1.76, df= 14, P= 0.000092), hand length (Paired T-test: one-tailed t= 1.76, df= 14, P= 0.03), and hand width (Paired T-test: one-tailed t= 1.76, df= 14, P= 0.003). In contrast, no significant morphological asymmetry was detected within the normal student population, nor among the golfers (Paired T-tests: one-tailed P-values > 0.05 for all four measurements) (Table 1).

TABLE 1. Measurements of forearm length, forearm circumference, hand length, and hand width for students, tennis players, and golfers

	Students	Tennis Players	Golfers
Forearm Length	Dom: 26.32 ± 2.15 [22.50 – 30.50] Opp: 26.33 ± 2.15 [22.50 – 30.00]	Dom: 25.59 ± 2.37 [22.10 – 31.50] Opp: 25.29 ± 2.23 [21.90 – 31.00]*	Dom: 24.38 ± 1.13 [23.00 – 26.20] Opp: 24.35 ± 0.99 [23.40 – 26.10]
Forearm Circumference	Dom: 25.64 ± 3.19 [20.00 – 32.60] Opp: 25.46 ± 3.22 [20.00 – 32.60]	Dom: 27.02 ± 1.92 [24.20 – 31.00] Opp: 25.72 ± 2.16 [22.50 – 30.20]*	Dom: 25.70 ± 1.50 [23.40 – 28.00] Opp: 25.54 ± 1.04 [24.20 – 27.00]
Hand Length	Dom: 17.83 ± 1.39 [15.50 – 21.50] Opp: 17.90 ± 1.37 [16.00 – 21.00]	Dom: 18.22 ± 1.41 [16.40 – 20.50] Opp: 17.97 ± 1.38 [15.70 – 20.10]*	Dom: 17.35 ± 0.61 [16.00 – 18.00] Opp: 17.26 ± 0.55 [16.20 – 18.10]
Hand Width	Dom: 7.41 ± 0.68 [6.35 – 8.90] Opp: 7.46 ± 0.70 [6.60 – 9.00]	Dom: 8.08 ± 0.71 [6.80 – 9.50] Opp: 7.94 ± 0.66 [6.90 – 9.30]*	Dom: 7.96 ± 0.26 [7.60 – 8.40] Opp: 7.96 ± 0.16 [7.70 – 8.20]

Dom = dominant arm; Opp = opposite arm
* = indicates the values for the opposite limb that are significantly ($P<0.05$) different from the dominant limb; other values are not significantly different ($P>0.05$).

4.2. Grip/Forearm Muscle Strength Analysis

Student Population

No significant differences were identified between the dominant and non-dominant limbs among the student population for grip strength (Paired T-test: one-tailed t= 1.71, df= 23, P= 0.36), wrist flexion force (Paired T-test: one-tailed t= 1.72, df= 20, P= 0.32), or wrist extensor force (Paired T-test: one-tailed t= 1.72, df= 20, P= 0.25) (Table 2).

TABLE 2. Maximum force in grip strength and wrist flexor/extensor muscles for the normal population of students

	Grip Strength	Wrist Flexion	Wrist Extension
Dominant hand	230.42 ± 93.02 [103.50 - 462.00]	68.72 ± 26.29 [38.68 – 154.50]	83.97 ± 31.79 [38.20 - 167.30]
Opposite hand	226.74 ± 98.78 [88.00 – 487.4]	66.61 ± 25.37 [26.00 – 130.30]	81.05 ± 36.69 [34.60 – 185.90]
Ratio	1.05 ± 0.22 [0.60 – 1.50]	1.06 ± 0.29 [0.76 – 1.61]	1.08 ± 0.23 [0.62 – 1.50]

Tennis Players

Significant differences were identified between the dominant and non-dominant limbs among the tennis players for grip strength (Paired T-test: one-tailed t= 1.76, df= 14, P= 0.0002), and wrist extensor force (Paired T-test: one-tailed t= 1.76, df= 14 , P= 0.0097). However, no significant differences were found for wrist flexion force (Paired T-test: one-tailed t= 1.76, df= 14, P = 0.13) (Table 3).

TABLE 3. Maximum force in grip strength and wrist flexor/extensor muscles for D1 collegiate tennis players (male and female)

	Grip Strength	Wrist Flexion	Wrist Extension
Dominant hand	292.38 ± 75.89 [139.90 - 475.80]	99.95 ± 29.88 [58.90 – 180.10]	121.86 ± 38.04 [84.20 – 213.10]
Opposite hand	242.11 ± 73.44 [161.80 – 414.50]*	93.55 ± 34.76 [65.60 – 179.40]	109.63 ± 36.77 [69.20 – 181.40]*
Ratio	1.24 ± 0.25 [0.76 – 1.67]	1.12 ± 0.26 [0.52– 1.55]	1.13 ± 0.16 [0.79 – 1.45]

* = indicates the values for the opposite limb that are significantly (P<0.05) different from the dominant limb; other values are not significantly different (P>0.05).

Golfers

No significant differences were identified between the dominant and non-dominant limbs among the golfers for grip strength (Paired T-test: one-tailed t= 1.94, df= 6, P= 0.41), wrist flexion force (Paired T-test: one-tailed t= 1.94, df= 6, P= 0.15), or wrist extensor force (Paired T-test: one-tailed t= 1.94, df= 6, P= 0.25) (Table 4).

Table 4. Maximum force in grip strength and wrist flexor/extensor muscles for D1 collegiate golfers (female only)

	Grip Strength	Wrist Flexion	Wrist Extension
Dominant hand	203.25 ± 38.28 [166.30 – 264.50]	69.73 ± 16.44 [53.10 – 101.30]	80.11 ± 16.12 [68.10 – 108.80]
Opposite hand	204.71 ± 33.33 [157.50 – 255.40]	63.98 ± 11.62 [42.40 – 80.60]	74.38 ± 8.61 [65.6 – 89.50]
Ratio	1.00 ± 0.15 [0.75 – 1.16]	1.11 ± 0.25 [0.72 – 1.55]	1.08 ± 0.23 [0.82 – 1.58]

Student Population vs. Tennis Players

Tennis players exhibited significantly greater grip strength asymmetry compared to the student sample (2-sample T-test: t= 2.04, df= 30, P= 0.019). However, this dissimilarity was not observed in the wrist extensor (2-sample T-test: t= 2.03, df= 36, P= 0.42) or flexor muscles (2-sample T-test: t= 2.05, df= 28, P= 0.45), which showed no significant differences between the two groups (Fig. 3,4, and 5).

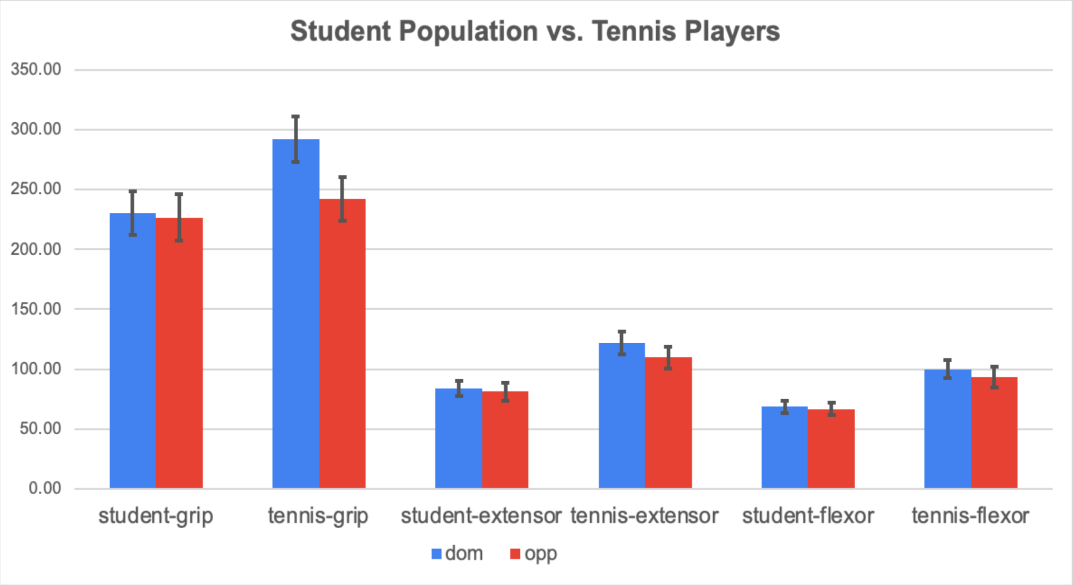

Fig. 3. Grip strength and wrist extensor/flexor muscles strength comparison between D1 collegiate tennis players and undergraduate students.

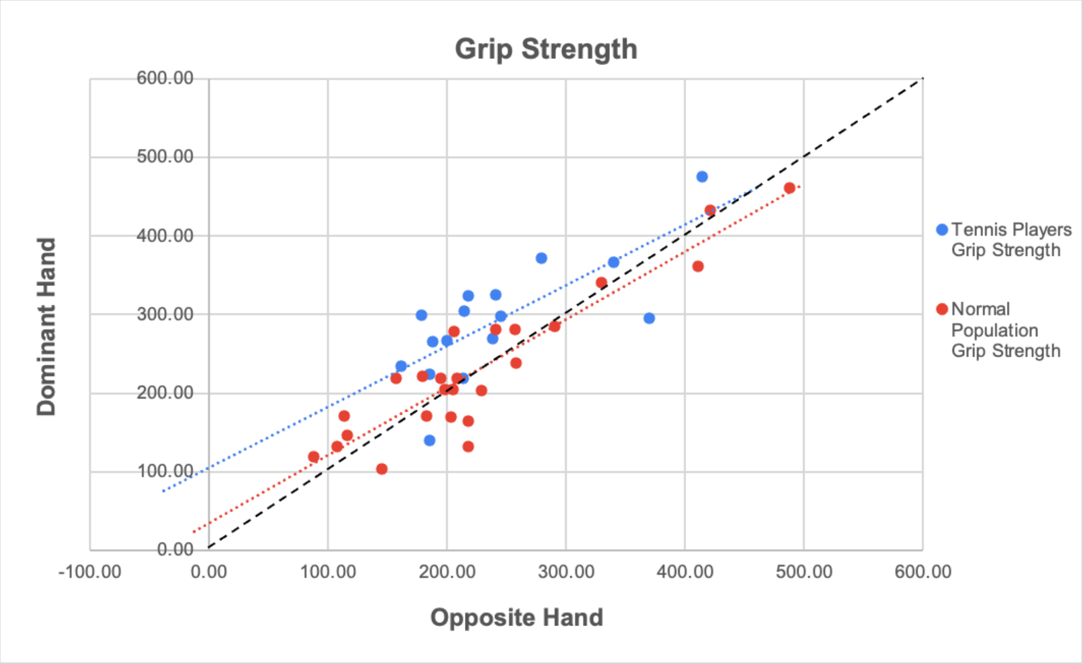

Fig. 4. Grip strength comparison between D1 collegiate tennis players and undergraduate students.

Fig. 5. Extensor muscles strength comparison between D1 collegiate tennis players and undergraduate students.

Female Student Population vs. Golfers

Golf players did not exhibit significantly greater grip strength, extensor muscles force, or flexor muscles force asymmetry when compared to the normal female population of students (2-sample T-test: P>0.5 for all three tests). (Fig. 6).

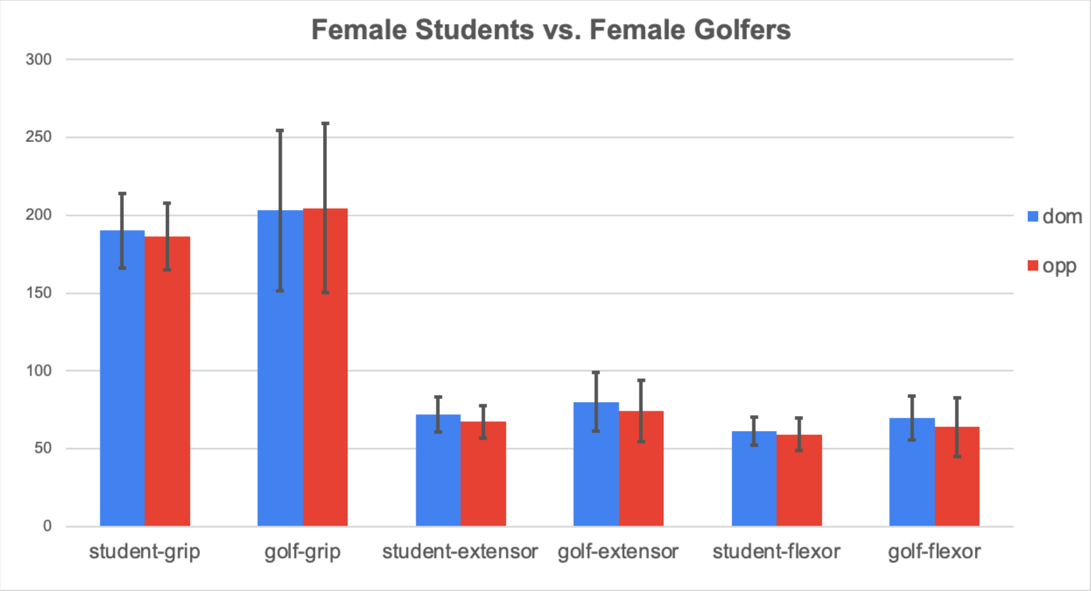

Fig. 6. Grip strength and wrist extensor/ flexor muscles strength comparison between D1 collegiate golfers and undergraduate students.

Overall, these findings underscore the unique physiological adaptations associated with intensive tennis training, particularly evident in grip strength asymmetry and morphometric characteristics of the dominant limb. On the other hand, golfers and the normal population did not demonstrate similar patterns of asymmetry or morphometric differences between their dominant and non-dominant limbs.

5. Discussion

This study investigated the patterns and asymmetries in wrist flexor and extensor muscles, as well as grip strength, among collegiate athletes engaged in asymmetric sports, specifically tennis and golf, with the goal of shedding light on the unique physiological adaptations associated with intensive asymmetrical training and muscle use in these sports. Our results strongly indicate that collegiate tennis players exhibit greater grip strength asymmetry compared to the normal population.

This observation aligns with previous research suggesting that athletes engaged in asymmetrical sports often develop disproportionate muscular strength between their dominant and non-dominant limbs.[1,5] The significant difference in grip strength asymmetry between tennis players and the normal population underscores the impact of sport-specific training on muscular adaptations.

Tennis players demonstrated significant differences between their dominant and non-dominant arms in grip strength. Grip strength is expected to be higher in the dominant arm of tennis players because it is the arm primarily responsible for holding and controlling the tennis racket and performing repetitive gripping motions. These actions require a strong grip to maintain control and generate power, leading to increased muscle development and strength in the dominant arm of tennis players.

Additionally, tennis players demonstrated significant differences between their dominant and non-dominant arms in wrist extensor strength. This asymmetry is also expected to be greater in the dominant arm of tennis players. Especially during the two-handed backhand stroke, wrist extensor muscles are significantly used to impose power and spin onto the ball. As a result, the wrist extensor muscles in the dominant arm undergo more intense and repetitive training, leading to greater strength compared to the non-dominant arm.

However, no significant asymmetry was observed in wrist flexor muscles. The lack of significant difference in wrist flexor muscles particularly was unexpected. There are several possible reasons for this observation. There is possibly a differential use of flexor and extensor muscles during tennis strokes, such as the backhand, which may not heavily engage flexor muscles in the dominant arm as much as extensor muscles. Another possible explanation for this lack of asymmetry is that the two-handed backhand engages the wrist flexors of the non-dominant arm considerably, such that the flexors of both arms are heavenly worked, and equally so, in training. In contrast, the asymmetry observed at the wrist extensors could have resulted from the forehand and backhand strokes working these muscles differently. Additional factors include varying effort levels from the subjects during testing and non-ideal experimental conditions, such as difficulties in pushing the handle of the force plate.

The morphometrics analysis revealed significant differences in forearm length, arm circumference, hand length, and hand width between the dominant and non-dominant arms among tennis players, indicating structural adaptations associated with intensive training in this sport. The significant differences in these measurements between the dominant and non-dominant arms among tennis players likely arise from the specific demands placed on the dominant limb during intensive training in the sport. Tennis involves repetitive and forceful movements, such as gripping the racket and executing powerful strokes, which lead to hypertrophy and increased strength in the muscles of the dominant arm. This asymmetrical muscular development can result in structural adaptations, including changes in bone length and circumference, as well as alterations in hand dimensions, to accommodate the increased muscle mass and strength induced by the sport. These morphometric differences were not observed in golfers or the normal population, further highlighting the sport-specific nature of physiological adaptations.

Muscle asymmetry in golfers is expected due to the one-sided nature of the golf swing, which predominantly engages muscles on one side of the body. During a golf swing, the dominant hand provides the majority of the power and control, while the non-dominant hand serves a supporting role, mainly guiding the club's path and maintaining stability. The dominant hand grips the club firmly and generates clubhead speed through the downswing, while the non-dominant hand maintains connection with the club and helps to guide its path, ensuring accuracy and consistency in the swing. Additionally, the rotational movement involved in swinging a golf club primarily recruits muscles in the dominant arm, shoulder, and torso, leading to greater development and strength asymmetry in these muscle groups compared to the muscles on their non-dominant side.

Contrary to the findings in tennis players, golfers did not exhibit significant differences between their dominant and non-dominant arms in grip strength or wrist flexor and extensor muscles. This discrepancy suggests that the nature of asymmetry in muscular strength may vary between different asymmetrical sports. While tennis involves rapid and forceful movements with both hands, golf predominantly relies on unilateral swinging motions, which may contribute to different patterns of muscular adaptation and asymmetry. Additionally, it is also possible that forces at the hand are not great enough in magnitude in golf players, or that they do not perform enough repetitions to induce muscle asymmetry.

However, several limitations should be considered when interpreting the results of this study. The sample size was relatively small, particularly for golfers, which may limit the generalizability of the findings. Additionally, the study focused exclusively on collegiate athletes and did not explore potential differences based on skill level or training intensity within the athlete population. Past research has shown that these factors can influence muscle activity and therefore affect its overall strength.[13] Studies suggest that recreational tennis players exhibit significantly higher extensor activity during most of the follow through phase compared to the experienced players, which can potentially put them at greater risk for developing lateral elbow tendinopathy.[8] Additionally, a study conducted with golfers showed that there also were significant differences in muscle activity of forearm muscles between professional and amateur golfers.[9] Future research incorporating larger sample sizes and considering additional factors, such as training volume and technique proficiency, could provide a more comprehensive understanding of muscular adaptations in asymmetrical sports.

The degree of effort that the subjects put into this research may be another limitation, as well as their forearm position. Although subjects were instructed to maintain a protonated hand position for all three tests, there could have been small inconsistencies in positioning. Past studies have shown that small changes in forearm position resulted in changes in grip strength, even though the rest of the body remained in the same standard position.[2]

This study demonstrates the significant grip strength and wrist extensor muscles strength asymmetry, as well as morphometric differences, observed among collegiate tennis players. Further research exploring the underlying mechanisms driving these adaptations and their implications for performance and injury prevention is needed. By advancing our understanding of muscular asymmetry in asymmetrical sports, this research contributes to the development of evidence-based training protocols and rehabilitation strategies tailored to the unique needs of athletes.

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7. References

1- Lucki N, Nicolay CW. 2007. Phenotypic plasticity and functional asymmetry in response to grip forces exerted by intercollegiate tennis players. Am J Human Biology 19 (4): 566-577.

2- Richards LG, et al. 1996. How Forearm Position Affects Grip Strength. Am J Occupational Therapy 50(2):133-138.

3- Martin C, et al. 2013. Upper limb joint kinetic analysis during the tennis serve: Assessment of competitive level on efficiency and injury risks. Scand J Med Sci Sports 24: 700–707.

4- Sakai R, et al. 2016. Analysis of Forearm Muscle Activity Aiming at Prevention of Refractory Tennis Elbow: Comparison of One-Handed Backhand Stroke Form. SM J Orthopedics 4(1): 1064s2.

5- Lijewski M, Burdukiewicz A, Pietraszewska J, Andrzejewska J, Stachoń A. 2021. Asymmetry of Muscle Mass Distribution and Grip Strength in Professional Handball Players. Int J Environ Res Public Health. 16;18(4):1913.

6- Hart NH, Nimphius S, Weber J, et al. 2016. Musculoskeletal Asymmetry in Football Athletes: A Product of Limb Function over Time. *Med Sci Sports Exerc*. 48(7):1379-1387.

7- Pradas F, Toro-Román V, Ortega-Zayas MÁ, Montoya-Suárez DM, Sánchez-Alcaraz BJ, Muñoz D. 2022. Physical Fitness and Upper Limb Asymmetry in Young Padel Players: Differences between Genders and Categories. *Int J Environ Res Public Health*. 19(11):6461

8- Rigozzi CJ, Vio GA, Poronnik P. 2023. Comparison of Grip Strength, Forearm Muscle Activity, and Shock Transmission between the Forehand Stroke Technique of Experienced and Recreational Tennis Players Using a Novel Wearable Device. *Sensors (Basel)*. 23(11):5146.

9- Farber, AJ., et al. 2008. Electromyographic analysis of forearm muscles in professional and amateur golfers. The American Journal of Sports Medicine, vol. 37, no. 2, pp. 396–401.

10- Kamien MA. 1990. Rational management of tennis elbow. Sports Med. 9(3):173-91.

11- Bohannon RW. 2001. Dynamometer measurements of hand-grip strength predict multiple outcomes. Percept Mot Skills. 93(2):323-8.

12- Massy-Westropp NM, Gill TK, Taylor AW, Bohannon RW, Hill CL. 2011. Hand Grip Strength: age and gender stratified normative data in a population-based study. *BMC Res Notes*. 4:127.

13- Gäbler M, Berberyan HS, Prieske O, et al. 2021. Strength Training Intensity and Volume Affect Performance of Young Kayakers/Canoeists. *Front Physiol*. 12:686744.